Shape evolution in semi-magic Sn-isotopes: A recent scenario

S. Dutt[1,*], M. Saxena[2], P. Doornenbal[3], A. Jhingan[4], A. Banerjee[5], R. K. Bhowmik[5,#], R. Garg[5], C. Joshi[6], V. Mishra[7], P. J. Napiorkowski[2], S. Prajapati[8], I. A. Rizvi[1], P. A. Söderström[3], H. J. Wollersheim[9], and R. Kumar[5]

[1]*Department of Physics, Aligarh Muslim University, Aligarh 202002, INDIA*
[2]*Heavy Ion Laboratory, University of Warsaw, Warsaw 02-093, POLAND*
[3]*RIKEN Nishina Center for Accelerator –Based Science, Wako, Saitama 351-0198, JAPAN*
[4]*Department of Physics & Astrophysics, University of Delhi, Delhi 110007, INDIA*
[5]*Inter University Accelerator Center, New Delhi 110067, INDIA*
[6]*Department of Physics, M.S. University of Baroda, Vadodara 390002, INDIA*
[7]*Department of Physics, Banaras Himdu University, Varanasi 221005, INDIA*
[8]*Department of Physics, Bareilly College, Bareilly 243005, INDIA*
[9]*Helmholtzzentrum fur Schwerionenforschung GmbH, D-64291, GERMANY*
** email: sunilduttamu@gmail.com # retired*

Study of the collective behaviour of nuclei and its relation to the underlying single particle configurations & their interactions is of the fundamental importance for the understanding of the evolution of nuclear structure with neutron number ‘N’ (or mass number ‘A’) and proton number ‘Z’. To understand these effects, isotopic chain of Sn-isotopes (Z=50), lying between two doubly magic cores and nuclei with only neutron degrees of freedom, is one of the best candidates in nuclear chart [1]. As explained in Ref-1, the information of valence proton-neutron interactions is helpful to predict the properties of unknown nuclei and correlate empirical values for these interactions with the onset of collectivity and deformation. Therefore, since the development of accelerators to date, several studies have been focused on these isotopes [1-8]. For Sn-isotopes anomalous deviations from the spherical picture were observed for the B(E2; $0_1^+ \rightarrow 2_1^+$) values as a function of ‘N’ (or ‘A’) [2-4]. Various models/theories were proposed to fit the experimental data but could only succeed for distinct regions, and hence a unified and precise description of these anomalies was missing.

In this work, we have given the summary of recent experimental results [2-4] for the determination of B(E2) values in the light of some theoretical models discussed in recent publications [5-7]. As shown in Fig.-1, Banu *et al.* [5] first presented the large-scale shell model (LSSM) calculations with ^{90}Zr and ^{100}Sn cores considering the effects of core polarisation

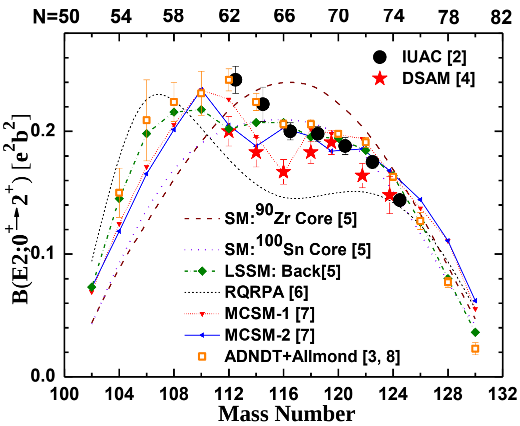

Fig. 1 Experimental/theoretical B(E2;$0^+ \rightarrow 2^+$) values of Sn isotopes [2-8] as a function of mass number/neutron number.

both for proton and neutron shells predicting a bell-shaped curve with maxima at mid-shell. Later, Ansari & Ring [6] attempted to justify the enhanced collectivity for neuron deficient Sn-isotopes with NL1 & NL3 parameters and Gogny’s pairing interaction in relativistic quasiparticle random-phase approximation (RQRPA) approach, which considers no core as an input but could only reproduce the shape of B(E2) systematic. An overall good agreement with experimental B(E2) values [2,3] was observed by Back *et al.* (especially for long puzzled neutron deficient Sn-isotopes [8]) by using multipole two body interaction with an isospin dependent effective charge which shows clear disagreement with DSAM measurements by Jungclaus *et al.* [4]. Recent microscopic

Monte Carlo shell model (MCSM) calculations performed by Togashi *et al.* [7] also exhibits a considerably good agreement with the data [8]. However, a dip at N=64 or 66 has also been predicted individually with two different sets of parameters, which can be correlated with the observed deviation of the 2_1^+ energy from the relevant experimental energy for these isotopes.

As shown in Fig. 2, Raman's best global fit formula [9] ($B(E2;0^+\rightarrow 2^+)=2.57\pm 0.45E_\gamma^{-1}Z^2A^{-2/3}$) based on the pioneering work of Bohr and Mottelson [10] and Grodzins formalism [11] provides a convincingly good agreement with data [2,3] around mid shell Sn-nuclei, however, it couldn't reproduce the experimental B(E2)s in the neighbourhood of double shell closures.

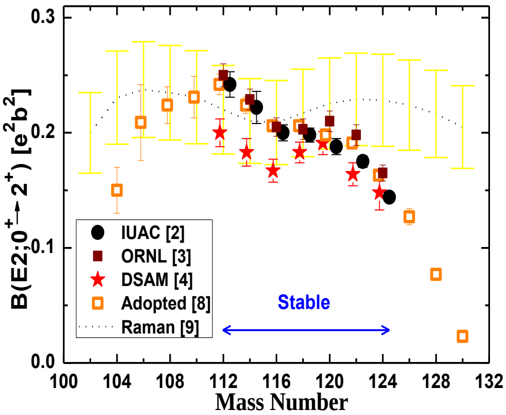

Fig. 2 Raman's predictions along with the experimental data for the semi-magic Sn chain.

In Fig. 3, a comparison of our recent work [2] with available data [3,4,8,12] for isotonic chains of N=64, 66 & 68 has been presented showing a bunch of B(E2) values at Z=50. B(E2) value for ^{116}Sn determined recently by Pore *et al.* [12] also replicate the Coulomb excitation data [2,3] contrary to DSAM measurement [4] and has been depicted in Fig. 3. Near the closed shell (Z=50) a sharp change in B(E2) values has also been observed which is nearly equal and independent of 2 proton particles or 2 proton holes structure. The figure signifies a strong effect of proton change as compared to the neutrons variation with the same proton number.

From the above discussions, we confer that the theoretical calculations discussed here show considerably good agreement with experimental B(E2) values, together with enhanced collectivity at N=54-60. The shell model calculations [5,7]

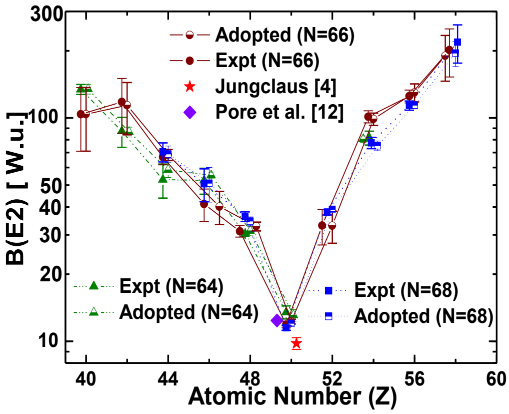

Fig. 3 B(E2) values as a function of atomic number (Z) at N=64, 66 & 68.

have given a reasonably good agreement with the experimental data points [2,3,8]. Some of the theoretical/experimental results (in particular DSAM measurements [4] and dip at N=64 or 66 by Togashi *et al.*) show some deviations from Coulomb excitation data. Nevertheless, one should be conscious that Coulomb excitation is the most appropriate and viable tool to study the low-level excitations in any nuclei.

[1] R. F. Casten and R. B. Cakirli, Phys. Scr. **91**, 033004 (2016); T. Faestermann et al., Prog. Part. Nucl. Phys. **69**, 85 (2013).
[2] R. Kumar *et al.*, Phys. Rev. C **96**, 054318 (2017) and references therein.
[3] J. M. Allmond *et al.*, Phys. Rev. C **92**, 041303(R) (2015).
[4] A. Jungclaus *et al.*, Phys. Lett. B **695**, 110 (2011).
[5] A. Banu *et al.*, Phys. Rev. C **72**, 061305(R) (2005); T. Back et al., Phys. Rev. C **87**, 031306(R) (2013).
[6] A. Ansari Phys. Lett. B **623**, 37 (2005).; Phys. Rev. C **74**, 054313 (2006).
[7] T. Togashi *et al.*, Phys. Rev. Lett. **121**, 062501 (2018).
[8] B. Pritychenko *et al.*, At. Data Nucl. Data Tables **107**, 1 (2016); www.nndc.bnl.gov
[9] S. Raman *et al.*, Phys. Rev. C **43**, 556 (1991); At. Data Nucl. Data Tables **78**, 1 (2001).
[10] A. Bohr and B. R. Mottelson Mat. Fys. Medd. Dan. Vid. Selsk **27**, No. 16 (1953).
[11] L. Grodzins *et al.*, Phys. Lett. **2**, 88 (1962).
[12] J. L. Pore *et al.*, Eur. Phys. J. A. **53**, 27 (2017).